

# Responses of the seedlings of five dominant tree species in Changbai Mountain to soil water stress

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**Abstract:** Soil water stress was studied on the potted seedlings of five dominant tree species (*Pinus koraiensis* Sieb. et Zucc., *Fraxinus mandshurica* Rupr., *Juglans mandshurica* Maxim., *Tilia amurensis* Rupr. and *Quercus mongolica* Fisch. ex Turcz.) from the broadleaved/Korean pine forest in Changbai Mountain. Leaf growth, water transpiration and photosynthesis were compared for each species under three soil moisture conditions: 85%-100% (high water, CK), 65%-85% (Medium water, MW) and 45%-65% (low water, LW) of 37.4% water-holding capacity in field. The results showed that the characteristic of typical drought-resistance of the leaves is significantly developed. The net photosynthetic rate and water use efficiency of *Fraxinus mandshurica* were higher in MW than those in CK. But for the other four species, the net photosynthetic rate and water use efficiency in CK were lower than those in MW and LW. The transpiration rate responding to soil moistures varied from species to species.

**Keywords:** Water stress; Net photosynthesis; Transpiration rate; Water use efficiency; Broadleaf/Korean pine forest

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## Introduction

Plant growth is regulated by genetic material and affected by environmental factors such as light, temperature and water, etc.. Therefore, the process of plant growth may reflect the change of environmental factors in a sense. Effect of environmental factors on plant growth is comprehensive. Identifying the dependency of plant growth on single environmental factor, especially on the main factors, is prerequisite for evaluating the interaction of environmental factors and responses of plants (Daubenmire 1974). Water is one of the most important environmental factors for plant growth and development. Water deficiency will restrict the whole growing process of plants including external and internal structure and metabolism. However, some studies showed that moderate water deficiency could enhance plant growth (Chang *et al.* 1999, Chazdon 1992), because there are differences in carbon assimilation and water use mechanism among different plants under soil water stress (Dai *et al.* 2000; Li *et al.* 1999; Li *et al.* 2000). In the past decades, researchers have done many studies on drought tolerance in crops and vegetables (Slavik 1974; Lange *et al.* 1976; Hsiao 1993; Collinson *et al.* 1999), and there was little information on dominant tree species of

terrestrial forest ecosystem. Although water is not a limiting factor for tree growth at high latitude of Changbai Mountain, the response of the forests in temperate zone of Changbai Mountain to water stress was poorly known (Wang *et al.* 1998). Climate warming tends to induce drought in most of region at low latitude of Changbai Mountain (Fu *et al.* 1996). A few researches reported the indirect effects of soil water stress regarding with the climate warming on some tree species in Changbai Mountain. So far, no relevant research having been carried out on the dominant tree species -- *Pinus koraiensis*, *Fraxinus mandshurica*, *Juglans mandshurica*, *Tilia amurensis*, *Quercus mongolica* in typical forest ecosystem of temperate zone. In present study the relationship between tree growth and soil water stress was investigated and analyzed for above species. We attempted to evaluate effects of various soil water stresses on: 1) leaf growth characteristics, 2) water status, and 3) photosynthesis. The study will provide data for predicting the adaptation and responses of forest at temperate zone against the possible coming drought.

## Materials and methods

### Study area

The experiment was carried out at the Opening Research Station of Changbai Mountain Forest Ecosystem, Chinese Academy of Science (Erdaobaihe town, Antu county, Changbai Mountain Natural Reserve Zone; 128°28'E, 42°24'N). The altitude of this site is 736 m. Mean annual temperature is 0.9-3.9 °C. The mean temperature in the coldest months is -16.7-18.6°C and that in the hottest months (July) is 17.4-20.7°C. The broadleaf/Korean pine forest is naturally distributed in this region. Soil type is the

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dark brown forest soil. This area belongs to a continental mountain climate, affected by monsoon and characterized by a dry and windy spring, warm rainy summer, dry and cold winter. Annual rainfall is 600-900 mm, with mostly from June to August. Frost-free period is 109-141 days. The detailed description of the study area was carried out by Fan (1992) and Chi (1981).

### Materials

The 2-year-old seedlings of *Pinus koraiensis*, *Fraxinus mandshurica*, *Juglans mandshurica* and *Tilia amurensis* were collected from the nursery of Dashiqiao Bureau of Changbai Mountain in Antu County of Jilin Province. On April 15, 2000, 180 well-grown seedlings with similar association in each tree species were selected. The 3-year-old seedlings of *Quercus mongolica* were collected in broad-leaf/Korean pine forest of natural reserve zone in Changbai Mountain on April 25, 2000.

### Experiment treatments

On May 5, 2000, the seedlings were planted in pots. The pot is 28 cm in diameter and 25 cm in height and contains 10-kg brown forest soil with moisture percentage of 37.4%, collected from broadleaf/Korean pine forest. Three seedlings were placed in each pot, and watering was carried out daily. Based on natural water content of soil in growing season, we designed three soil water gradients as 85%-100 % (High water--CK), 65%-85% (medium water--MW), and 45%-65% (Low water--LW) of the field capacity. To each gradient we prepared 20 pots for one tree species, totally 300 pots for 5 tree species. All pots were put inside the hob. The top of the hob was exposed to sunshine and covered with tarp when it was raining. The seedlings were cultivated from May 1 to September 30, 2000. Water was supplied only in the afternoon of the same day for all treatments. In order to maintain the level of soil water content, we added water into pots in time, and in the evening checked the soil water content using soil moisture probe type HH2 meter.

### Methods

Relative water content of the leaves (RWC) was measured by saturated weighing method (Lin *et al.* 1982). The samples were collected from the top of trees, and fresh leaves (fully expanded and sunlit) were weighed immediately, then incubated at 105°C to deactivate the leaves, after then they were dried at 85°C to constant weight. RWC was calculated according to the method of Dai (2000). Free water content was measured using the reflective meter (2WAT). The bound water content is expressed as:

Bound water content (%) =  $\frac{\text{water content in fresh weight} (\%) - \text{free water content} (\%)}{100}$

Free water content (%) =  $\frac{B(B_2 - B_1)}{(B_2 \times W_f) \times 100}$

where B is 60% sugar liquid weight;  $B_1$  the sugar concentration at room temperature (20°C);  $B_2$  the sugar concen-

tration after the samples were immersed at 20°C for 5 hours;  $W_f$  is fresh weight. Bound water was calculated by the above formula (Zhang *et al.* 1980).

From 25th to 28th July, small random-sized samples (6 seedlings from each treatment) were measured to determine leaf dry weight and specific leaf area (SLA). Photosynthesis was measured in July, using an ADC4 portable photosynthesis analysis system, with three seedlings in each treatment. Measurements were made under 500-1 200  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ . Respiration rate was measured under dark light. In the meanwhile leaf water potential was measured using TRUPSI portable instrument (Australia ICT Company), soil water content was weighed and repeated in triplicate. The pine leaves was stuck to transparent tape and leaf area was measured.

### Data analysis

One-way ANOVA analysis of variance was applied to performing the results including leaf characteristics, and leaf water status, and photosynthetic parameters for different tree species under soil water stresses. All data were analyzed by the SigmaStat 2.03 procedure of SAS (SAS 1995).

### Results

#### Effect of soil water stress on leaf succulence parameters

Various soil water stresses had significant effects on the morphological characteristics of leaves of different tree species (Table 1). As soil water contents increased, leaf area, specific leaf area, leaf water content, and degree of succulence also increased. The leaf length of *Pinus koraiensis* was remarkably inhibited by water stress and it reduced with decrease of soil water. There was no significant difference in leaf thickness for 4 broadleaf tree species among various soil water levels, which tended to decline with increase of soil water. The change of leaf area for *Pinus koraiensis*, *Traxinus mandshurica*, *Tilia amurensis* and *Juglans mandshurica* had a similar trend under various water stresses and reduced with decrease of soil water. Leaf thickness and specific leaf area were also affected by the soil water levels. The results were consistent with the study on *Chenopodium album* (Sun 1999).

The increases of leaf thickness and degree of succulence and the reduction of leaf area enhanced the resistance of tree species to drought (Larcher 1980). When the plants were subjected to water stress, the most sensitive process was leaf-expanding growth. The decrease of specific leaf area implicated the reduction of leaf area per unit weight. The increases of internal tissue density of leaves and degree of succulence were the feature of xerophytic structure. Reduction of leaf water loss and inhibition of leaf transpiration in the seedlings resulted in less soil water being absorbed.

### Effect of soil water stress on leaf water status

After treated with stimulating drought, we found that there were significant differences in the relative water contents of leaf of 5 tree species between various soil water stresses (Table 2). The difference of water potential of leaf was not statistically significant for 5 tree species between various soil water stresses, but it decreased with reduction of soil water. The contents of free water and bound water of leaf in 5 tree species were proportional to the level of soil water. The relative water content of leaf, water potential of leaf, and natural saturation deficit declined with the decrease of soil water, however the responses were different. The relative water content of leaf of *Quercus mongolica* decreased significantly with the decrease of soil water, which decreased by 23.5% in LW group compared with that in CK group. In LW group, the leaf water content of *Fraxinus mandshurica* was the highest and that of *Quercus mongolica* was the lowest. Saturation water deficit of *Quercus*

*Mongolica* was higher. The results indicated that *Quercus mongolica* could more easily get water from soil than other tree species for surviving.

Relative water content in trees was consistent with the level of soil water. Leaf water content of 5 tree species decreased significantly with the decrease of soil water. However, with soil water further decreasing (LW group), leaf water content would not reduce and keep basic stabilization. The change of leaf water potential was not consistent with that of leaf water content. Since soil water decreased, the transpiration of leaf reduced and water fluxes can be regulated to decrease the requirement for water. Thus, the tree can maintain the cellular osmoregulatory capability. Only when soil water reduces to certain point and water in a tree is not able to meet the need of transpiration through resistance regulation of water fluxes, the leaf water potential would decline (Li 2000).

**Table 1 Effect of soil water stress on leaf succulence parameters of 5 tree species**

Species	Treatments	Leaf thickness /mm	Specific leaf area /Dm <sup>2</sup> · g <sup>-1</sup> · dry · wt	Water content /g · dm <sup>-2</sup>	Degree of succulence /FW · dm <sup>-2</sup>	Leaf area /cm <sup>2</sup>
<i>Pinus koraiensis</i>	CK	38.9±0.121a	1.11±0.07a	1.62±0.01b	2.49±0.03c	27.76±1.34a
	MW	34.9±0.111b	0.76±0.07b	1.68±0.07b	3.67±0.07b	24.87±1.22ab
	LW	30.8±0.098c	0.42±0.01c	3.33±0.11a	4.69±0.12a	23.86±1.43b
<i>Fraxinus mandshurica</i>	CK	0.117±0.023b	2.55±0.02a	1.43±0.02c	2.00±0.03c	11.98±2.67a
	MW	0.133±0.029a	1.75±0.08b	1.56±0.02b	2.22±0.02b	8.95±0.84ab
	LW	0.150±0.003a	1.44±0.04c	1.75±0.03a	2.44±0.02a	8.08±1.22b
<i>Juglans mandshurica</i>	CK	0.050±0.001b	2.94±0.04a	0.84±0.01b	1.19±0.03c	31.15±5.30a
	MW	0.055±0.007b	2.45±0.08b	0.85±0.02b	1.26±0.01b	22.83±3.79b
	LW	0.070±0.003a	2.37±0.06bc	0.99±0.02a	1.41±0.04a	21.67±4.17bc
<i>Tilia amurensis</i>	CK	0.108±0.038a	2.60±0.06ns	0.71±0.02b	1.11±0.01a	29.04±5.39a
	MW	0.125±0.041a	2.55±0.04ns	0.73±0.03b	1.13±0.02a	23.78±3.77ab
	LW	0.131±0.035a	2.50±0.04ns	0.79±0.02a	1.19±0.03a	21.03±2.37b
<i>Quercus mongolica</i>	CK	0.097±0.007a	3.38±0.08a	0.79±0.01b	1.10±0.02c	30.64±5.25a
	MW	0.107±0.012a	2.11±0.05b	0.56±0.02c	1.25±0.03b	27.64±5.79b
	LW	0.112±0.013a	1.29±0.03c	0.93±0.03a	1.70±0.03a	19.21±3.70c

Data in the table represent average value; Values in column not followed by the same letter are significantly different at  $P<0.05$ , ns represents  $P>0.05$ , as determined by Duncan multiple-rang test. CK: 85%-100%, MW: 65%-85%, and LW: 45%-65%.

Free water, bound water and their ratio were closely related to tree growth and drought hardiness (Zhang *et al.* 1980). When free water in a tree is relatively high, the metabolism is active and the tree grows well. The higher the ratio of bound water to free water is, the stronger the resistance to drought is (Lu *et al.* 1994; Shan *et al.* 1991). After stimulated drought for 5 tree species, we found that free water and bound water were lower in LW and MW groups than those in CK group and they were proportional to soil water level (Table 2). The ratio was inversely proportional to soil water level. Except for the ratio of *Quercus mongolica* in was higher in MW group than those in CK and LW groups, the ratios of other tree species were higher in CK group than those in MW and LW groups. It is obvious that *Quercus mongolica* has better resistance to drought.

### Effect of soil water stress on net photosynthetic rate of leaf

The effect of soil drought treatment on net photosynthetic rate of leaf of 5 tree species was significant by *t*-test, and the results were further analyzed by Duncan multiple-range test. Net photosynthetic rate of leaf decreased with the decrease of soil water (Table 3). Except for *Fraxinus mandshurica*, the net photosynthetic rates of other 4 tree species were significantly different between various soil water treatments ( $P<0.05$ ). The net photosynthetic rate of *Fraxinus mandshurica* has no significant difference between CK and MW groups. In CK group, net photosynthetic rates of 5 tree species varied from 4.73 to 12.38  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ , and the order from big to small was *Juglans*

*mandshurica* > *Pinus koraiensis* > *Tilia amurensis* > *Fraxinus mandshurica* > *Quercus mongolica*. In MW group net photosynthetic rates were from 3.26 to 12.48  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ , and their average was lower 15.18% than that in CK group. In LW group net photosynthetic rates varied from 2.43 to 7.89  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  and the average was lower 38.8% than that in CK group.

#### Effect of soil water stress on leaf stomatal conductance, transpiration rate and water use efficiency

Effect of soil water stress on stomatal conductance was different in 5 tree species by *t*-test. Stomatal conductance of 5 tree species was significantly different among soil water treatments. The stomatal conductance in *Fraxinus mandshurica* and *Juglans mandshurica* decreased significantly and the changing ranges of conductance were bigger than those in *Pinus koraiensis*, *Tilia amurensis* and *Quercus mongolica* (Table 3). Stomatal conductance and transpiration rate in *Fraxinus mandshurica* and *Tilia*

*amurensis* decreased with the decrease of soil water. The change of stomatal conductance was completely different from net photosynthetic rates of 5 tree species under various soil water stresses. Soil water stress obviously inhibited photosynthesis of seedlings, and net photosynthetic rate was proportional to soil water level. Stomatal conductance was not correlated to net photosynthetic rate in various soil water stresses (*F*-test), which indicated that stomatal conductance was not the main factor affecting net photosynthetic rate. A decrease of net photosynthetic rate resulted from the changes of water content and water potential, which affect electron transferring, enzymatic activities of photophosphorylase (Havaux & Canaani 1986) and RuBP carboxylase (Boyer 1976) of chloroplasts. Stomatal conductance was closely related to leaf vapor pressure deficit (VPD) and effect of VPD on stomatal conductance was significant by *F*-test ( $P < 0.05$ ). High vapor pressure deficit in leaves can induce stomatal closure (Jone 1998; Maroco *et al.* 1997).

**Table 2** Effect of soil water stress on water status of 5 tree species

Species	Treatment	RCW /%	$\phi w$ /bars	WSD /%	Free-water /%	Bound-water /%	Free-water/ Bound-water
<i>Pinus koraiensis</i>	CK	63.83 $\pm$ 2.11a	-19.7 $\pm$ 0.1	36.17 $\pm$ 2.22b	28.90	34.93	0.83
	MW	59.80 $\pm$ 2.13b	-20.0 $\pm$ 0.1	40.20 $\pm$ 2.31ab	25.76	34.04	0.77
	LW	58.14 $\pm$ 1.23b	-20.9 $\pm$ 0.2	41.86 $\pm$ 1.45a	25.22	32.92	0.77
<i>Fraxinus mandshurica</i>	CK	78.46 $\pm$ 2.34a	-20.0 $\pm$ 0.1	21.54 $\pm$ 2.21b	32.36	46.10	0.70
	MW	75.38 $\pm$ 1.76a	-20.3 $\pm$ 0.1	24.62 $\pm$ 1.43ab	28.16	47.22	0.60
	LW	69.64 $\pm$ 1.87b	-22.9 $\pm$ 0.2	30.36 $\pm$ 2.00a	25.34	44.30	0.57
<i>Juglans mandshurica</i>	CK	74.53 $\pm$ 2.76a	-19.8 $\pm$ 0.1	25.47 $\pm$ 1.76b	31.44	43.09	0.73
	MW	68.65 $\pm$ 1.21ab	-20.7 $\pm$ 0.1	31.35 $\pm$ 1.11a	27.80	39.85	0.70
	LW	67.35 $\pm$ 0.89b	-23.8 $\pm$ 0.1	32.65 $\pm$ 1.23a	25.49	41.8	0.61
<i>Tilia amurensis</i>	CK	68.98 $\pm$ 1.53a	-19.9 $\pm$ 0.2	31.02 $\pm$ 1.76b	33.46	35.52	0.94
	MW	65.35 $\pm$ 1.45ab	-20.2 $\pm$ 0.1	34.65 $\pm$ 1.23ab	31.75	33.60	0.94
	LW	63.87 $\pm$ 0.32b	-22.6 $\pm$ 0.1	36.13 $\pm$ 1.01a	30.13	33.74	0.89
<i>Quercus mongolica</i>	CK	71.09 $\pm$ 1.76a	-20.1 $\pm$ 0.1	28.91 $\pm$ 1.87c	35.16	35.93	0.98
	MW	64.40 $\pm$ 2.54b	-20.5 $\pm$ 0.1	35.60 $\pm$ 2.11b	32.28	32.12	1.00
	LW	54.40 $\pm$ 1.32c	-20.7 $\pm$ 0.1	45.6 $\pm$ 1.66a	26.51	28.00	0.95

RCW: relative water content;  $\phi w$ : water potential of leaf; WSD: natural water saturation deficit

Various soil water levels affected water use efficiency of seedlings of 5 tree species. Response of water use efficiency of 5 tree species to soil water stress was different. The water use efficiency of *Pinus koraiensis* and *Fraxinus mandshurica* was the highest, and that of *Quercus mongolica* was the lowest. In MW group, water use efficiency of *Pinus koraiensis*, *Juglans mandshurica* and *Tilia amurensis* was higher than that in CK and LW group. Water use efficiency tended to decrease with further decreasing soil water. The change of water use efficiency was not similar among 5 tree species in CK group. Because the responses among various tree species to soil water stress were different. Under water stress, photosynthetic rate of trees was not related to transpiration (McCree *et al.* 1989). The response of photosynthesis was not completely consistent with the change of transpiration. Namely photosynthesis of

trees is affected by stoma and non-stoma factors (Tang *et al.* 1983).

#### Discussion

Selye (1973) put forward the theory of drought hardening of plants in 1970s. According to this theory the plants growing under drought could improve drought tolerance to some extents. Zhu (1996) considered that drought hardening could enhance the drought tolerance of *Pinus sylvestris* var. *Mongolica*. After stimulated drought treatments, the changes of the water parameters, including water contents, water potential, saturation deficit, ration of free water to bound water, indicated that drought resistances of 5 tree species were enhanced with the increase of water stress levels. There was significantly difference compared with CK

group ( $P<0.05$ ). The typical drought-resistant plants are characterized by the thick leaf, small leaf area and high degree of succulence (Li 1981). Up to date, few reports were found about the changes of transpiration and stomatal conductance of leaves of arboreal species after long-term drought treatment. In present study the results showed that stomatal conductance of leaf was positively correlated to the transpiration rate for seedlings treated with stimulating drought. Photosynthesis and transpiration were the processes for  $\text{CO}_2$  and  $\text{H}_2\text{O}$  exchange, respectively, inside and outside the leaves. Stomatal conductance was positively correlated to transpiration (Xiao *et al.* 2001), which was similar to our study. In general, the higher stomatal conductance is, the faster transpiration rate is. Stomatal movement is affected by many factors. In our study vapor pressure deficit in air cavity of leaves was related to

stomatal conductance. Meinzer (1982) found that stomatal opening of Douglas fir was mainly affected by vapor pressure deficit, and the transpiration is controlled by stoma. Kramer (1983) considered that in some cases stoma could not be well regulated by transpiration. For seedlings of *Pinus koraiensis*, *Fraxinus mandshurica*, *Tilia amurensis* and *Quercus mongolica*, the transpiration was well regulated by stoma under soil water stress, and stomatal conductance was positive correlated to the transpiration rate ( $r=0.735, 0.783, 0.799$ , and  $0.785$ ,  $n=12$ ). But for *Juglans mandshurica*, the stomatal conductance was not related to transpiration rate in soil water stress ( $P>0.05$ ). Midgley (1993) had reported the similar results about the drought cycling of perennial shrubs in South Africa. Such response might prolong growing season and was resistant to fatal water stress.

**Table 3. Effect of soil water status on photosynthetic rate, transpiration rate, stomatal conductance and water use efficiency of 5 tree species**

Species	Treatment	Photosynthetic rate $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$	Transpiration rate $\text{mmol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$	Stomatal conductance $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$	Vapor Pressure deficit /Mpa	Water use efficiency rate $\mu\text{mol} \cdot \text{mmol}^{-2}$
<i>Pinus koraiensis</i>	CK	10.654 $\pm$ 1.557b	0.871 $\pm$ 0.112b	0.142 $\pm$ 0.016b	0.564 $\pm$ 0.018a	12.397 $\pm$ 2.337b
	MW	12.480 $\pm$ 1.650a	0.936 $\pm$ 0.086a	0.184 $\pm$ 0.016a	0.479 $\pm$ 0.0128c	13.41 $\pm$ 1.898a
	LW	7.887 $\pm$ 1.008c	0.654 $\pm$ 0.063c	0.108 $\pm$ 0.008c	0.556 $\pm$ 0.018ab	12.095 $\pm$ 1.358b
<i>Fraxinus mandshurica</i>	CK	6.078 $\pm$ 0.347a	0.955 $\pm$ 0.201a	0.088 $\pm$ 0.010a	0.895 $\pm$ 0.035c	7.159 $\pm$ 0.882b
	MW	6.548 $\pm$ 0.463a	0.862 $\pm$ 0.120b	0.064 $\pm$ 0.011b	1.352 $\pm$ 0.0687b	7.143 $\pm$ 1.450b
	LW	5.643 $\pm$ 0.964b	0.366 $\pm$ 0.092c	0.0181 $\pm$ 0.005c	2.474 $\pm$ 0.104a	15.738 $\pm$ 1.580a
<i>Juglans mandshurica</i>	CK	12.383 $\pm$ 0.713a	4.408 $\pm$ 0.235a	0.302 $\pm$ 0.016a	1.409 $\pm$ 0.019c	2.812 $\pm$ 0.141c
	MW	5.497 $\pm$ 0.365b	0.692 $\pm$ 0.096c	0.042 $\pm$ 0.006c	1.481 $\pm$ 0.027b	8.051 $\pm$ 0.924a
	LW	4.077 $\pm$ 0.865c	1.224 $\pm$ 0.707b	0.060 $\pm$ 0.016b	1.713 $\pm$ 0.662a	4.745 $\pm$ 2.869b
<i>Tilia amurensis</i>	CK	8.868 $\pm$ 0.153a	3.523 $\pm$ 0.086a	0.143 $\pm$ 0.009a	2.288 $\pm$ 0.054c	2.518 $\pm$ 0.066c
	MW	8.288 $\pm$ 0.273b	2.351 $\pm$ 0.088b	0.095 $\pm$ 0.002b	2.317 $\pm$ 0.095ab	3.528 $\pm$ 0.105a
	LW	5.989 $\pm$ 0.361c	1.818 $\pm$ 0.087c	0.072 $\pm$ 0.002c	2.335 $\pm$ 0.06a	3.295 $\pm$ 0.020b
<i>Quercus mongolica</i>	CK	4.727 $\pm$ 1.032a	1.763 $\pm$ 0.137b	0.077 $\pm$ 0.007b	2.062 $\pm$ 0.045b	2.659 $\pm$ 0.409a
	MW	3.263 $\pm$ 0.648b	2.118 $\pm$ 0.070a	0.104 $\pm$ 0.001a	1.907 $\pm$ 0.051c	1.541 $\pm$ 0.308c
	LW	2.433 $\pm$ 0.422c	1.285 $\pm$ 0.091c	0.057 $\pm$ 0.003c	2.123 $\pm$ 0.019a	1.907 $\pm$ 0.395b

Data of the table represent average value. Treatment with the same letters is not significantly different ( $P<0.05$ ) according to Duncan multiple range test.

Water use efficiency is an important integrated index for the relationship between water consumption and substance formation. It was studied at the levels of single leaf, whole-plant and community (Wang *et al.* 1997). Water use efficiency of plants was higher in middle water stress and the compensating growth was found in single leaf or whole plant (Midgley *et al.* 1993). We also got some results about 4 tree species except for *Quercus mongolica* (Table. 1), found that complicate changes occurred in the water consumption, and eco-physiological characteristics of trees. Net photosynthetic rate, stomatal conductance, and transpiration rate decreased to various degrees under soil water stress. Photosynthesis and transpiration were affected by stomatal conductance. In MW group, water use efficiency of seedlings of *Pinus koraiensis*, *Fraxinus mandshurica*, *Juglans mandshurica* and *Tilia amurensis* increased or had not significant change compared with that of

CK group. Because the effect of middle water stress on leaf transpiration exceeded the capability of leaf carbon fixation (Zhu *et al.* 1996). With the soil water stress increased, water use efficiency decreased. Because severe water stress destroyed photosynthetic organelles and reduced the relevant enzymatic activities of leaves and the decline of photosynthetic capacity exceeded the decrease of transpiration (Xu 1997). The water use efficiency of *Quercus mongolica* was lower in MW group than that that in CK group. And in MW group water potential of *Quercus mongolica* was higher than that in CK group. Thus leaf transpiration rate was increased, and water use efficiency was decreased. Compared with other tree species, *Quercus mongolica* in LW group could keep higher water potential to control transpiration and reduce the demand of soil water in tree crown.

In summary, we found that effects of soil water stress on

morphological and gas exchange parameters of leaves of 5 dominant tree species in the broadleaf/Korean pine forest of Changbai Mountain were remarkable. The ecosystem of broadleaf/Korean pine forest in northeast of China will make greatly change in future with drought. Therefore, how to manage the nature resource of broadleaf/Korean pine forest for ecosystem development is a very important work.

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